Not too hot, not too cold

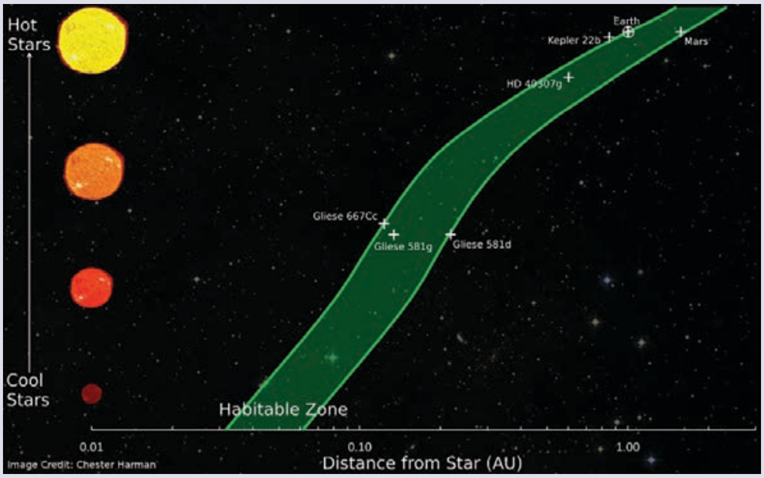
by Bob Riddle

My November 2014 column, about how we detect exoplanets (see Riddle 2014 in Resources), is a good lead-in to the search for exoplanets that are Earthlike in both location relative to their host star and the physical properties of the planets based on their location. If we are looking for Earthlike planets orbiting other stars, then a logical place to expect to find them would be at an Earth-to-Sun type distance from the star they orbit. However, the Earth-to-Sun distance "rule" does not apply to all stars, as not all stars are like ours—the Sun. Stars are found in a variety of sizes and temperatures. So astronomers have developed a model that takes into consideration the type of star based on the star's mass and temperature. Using that information, astronomers can calculate the distance an Earthlike planet could be located from that star.

Astronomers refer to the location of the Earth relative to the Sun as being within a region called the habitable zone. Also known as the *Goldilocks zone*, this is a region around any star that is at a distance where a planet could have an Earthlike global temperature, allowing for water to be in liquid form. Figure 1 illustrates the location of the Goldilocks zone relative to different types of stars. To date, there have been more than 4,000 space objects detected, nearly 1,000 of which have been confirmed as exoplanets. (Since there is not a standard method for qualifying suspected objects as exoplanets, but rather different techniques and qualifying criteria, the count of exoplanets varies.) Less than two dozen of the latter have been confirmed as being within their respective habitable zones, meaning that the majority of exoplanets discovered so far are not within a habitable zone.

The habitable zone around a star is determined through a series of calculations that use our Sun's physical properties as a constant value for comparison. Then the star's absolute luminosity (the actual energy output of the star, which we typically refer to as the star's *absolute magnitude*) is calculated, and this calculation is entered into another equation used to determine the radius of the habitable zone (see Calculating the Habitable Zone in Resources).

FIGURE 1 The habitable zone for various stars



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The website Habitable Zones in Multiple Star Systems (see Resources) allows you to enter various values into an online calculator that determines and then graphically displays the habitable zone for single-, binary-, and multiple-star systems. This website, which involves skills that are probably more advanced than what is covered in middle school science classes, gives students a virtual sandbox within which they can experiment with different star systems and planets. The graphic displays also make the website a much more visual experience than just using simple data tables and graphs.

Exploring exoplanets

In the Resources are links to several websites and software that could be used by students in the classroom as they learn more about exoplanets and exosystems or create their own fictional solar system.

To reinforce the transit method (see Riddle 2014 in Resources) as a primary method for detecting exoplanets, use the Java-based freeware Exoplanet Detection Software to show students a simulation of a transiting planet and the light curve it produces. (The *transit method* involves observing a star's decrease in brightness due to the passage of a planet across the disk of the star, or a *transit*, as we see the two from Earth.) Follow this up with the Circumstellar Habitable Zones Lab simulator (see Resources). Both simulators could be used as a whole-class demonstration of a habitable zone around a star. The Circumstellar Habitable Zone simulator allows users to change the settings for the planet's distance from the star and the star's mass, which in turn changes the values of the star's luminosity, temperature, and size and the location of its habitable zone. The simulator also allows users to move forward or backward in time to see how the habitable zone is affected as the star increases and decreases in size as it ages.

To follow up these demonstrations of transiting exoplanets and habitable zones, students can look at data tables about exoplanets. There are several websites for this, as well as several websites that list differing totals of detected and confirmed exoplanets. One such website is the Planet Habitability Laboratory at the University of Puerto Rico at Arecibo. This site is one-stop shopping for information relating to exoplanets, including a very comprehensive listing of them. The Planetary Biology website is also useful and lists exoplanets. At this website, there is a list of over 1,800 exoplanets, complete with data about each planet and its host star. Each star name is linked to another website with additional information about the star. What makes this website stand out is the downloadable freeware program exoExplorer. This is a Windows-based program that developers created to translate information from the data tables on the Planet Habitability Laboratory website into visualizations of exoplanet environments. With the program and access to the exoplanet database, students can create virtual trips in a 3-D environment that take them across space to other star systems, where they can orbit an exoplanet and even fly above or drive on an exoplanet's surface.

Despite its name, Super Planet Crash is a great way to observe the gravitational effects that planets have on other planets in their star system and how orbits change when the type or number of stars is also changed. It is a game-based simulation that allows the user to create a fictional solar system using planets of varying masses, as well as different types and numbers of stars. The goal is to create a solar system that lasts for at least 500 years and accumulate as many points as possible. Points are awarded based on the planets and stars used, and the highest scores are posted on the website, which will perhaps serve as an incentive for students. In addition to the simulation, the website links to several other websites with information about exoplanets.

Exoplanet art/science project

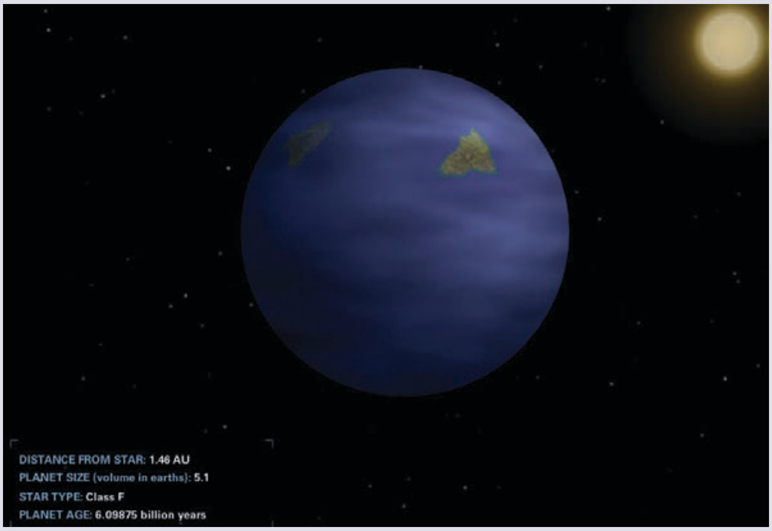
In this project, students create their own fictional exoplanet using the freeware program StarGen (Windows and Mac; see Resources). With this program, students can put together their own unique, fictional solar system or experiment with star properties of known or fictional stars to see what sort of planets could be found orbiting that type of star, including habitable planets. An alternative and considerably less time-consuming project could involve the NASA website Extreme Planet Makeover instead (see Resources). On this website, students are able to input some basic values, such as mass and distance from the star, to determine how a planet may look as a result. The planets in our solar system are listed, and each could be used as a starting point for a planet makeover (see Figure 2).

Depending on how cosmic you want your students to go, their newly created worlds could be plotted on a star map using the online Distant Worlds Star Mapper to make a star chart of the region in space surrounding their star and exoplanet (see Resources).

Solstice and meteors

In addition to the holidays, December is also known for the December solstice, at which time fall changes to winter in the Northern Hemisphere, while in the southern hemisphere the opposite occurs. Decem-

FIGURE 2 Earth after an "extreme planet makeover"



ber also has its share of meteor showers (see Meteor Showers Online in Resources). Most notable is the Geminid meteor shower, which will peak this year on December 13 and can be seen anywhere the Gemini constellation is visible during night hours. Usually meteor showers are best viewed during the early morning hours, as the side of Earth you are on faces into the meteors as they enter the Earth's atmosphere. However, the Geminids rise in the evening during December and radiate from a point near the star Castor in the Gemini Twins constellation. Castor is the "upper" of the two twin stars as they become visible above the eastern horizon at sunset local time. The Geminids have a zenith hourly average rate (ZHR) that ranges up to about 80 per hour, depending on sky conditions. This year, the last quarter Moon will rise around midnight, so there are a few hours during which the Geminids may be seen before the Moon rises, brightening the sky and dimming all but the brightest meteors.

During December there are a total of eight meteor showers, including the Geminids. Of the other meteor showers, the best is probably the Ursids. This meteor shower radiates from a point near the bowl of the Little Dipper and peaks during the evening of December 22, with a ZHR of up to 10. Once in a while there can be an outburst where the ZHR jumps to around 100. With that in mind, it may be worthwhile to encourage students to go outside during that evening and look north for the Ursids. ■

Visible planets

Mercury will move out from behind the Sun at superior conjunction and become visible in the evening skies over the western horizon during the last week of the month.

Venus, like Mercury, will start becoming visible above the western horizon after sunset as an evening planet.

Mars will be visible but low over the western horizon at sunset.

Jupiter will rise several hours after sunset local time and will be visible the rest of the night.

Saturn will start becoming visible over the eastern horizon in the morning skies, rising before the Sun.

December

2	Moon at descending node
5	Waxing gibbous Moon near Aldebaran
6	Full Moon
8	Mercury at superior conjunction
9	Jupiter begins retrograde motion
	Waning gibbous Moon near Gemini Twins
10	*Cassini* flyby of Titan
12	Moon at apogee: 404,600 km (251,407 mi.)
	Mars at perihelion
	Waning gibbous Moon near Jupiter
13	Mars at heliocentric conjunction with Neptune
	Geminid meteor shower: ZHR = 80
14	Last quarter Moon
16	Moon ascending node
17	Waning crescent Moon near Spica

18	Sun enters Sagittarius (astronomical)
19	Waning crescent Moon near Saturn
21	December solstice (6:03 p.m. EST)
	Sun enters Capricorn (astrological)
	New Moon
22	Uranus ends retrograde motion
	Ursid meteor shower: ZHR = 10
23	Waxing crescent Moon near Venus
24	Moon at perigee: 364,800 km (226,676 mi.)
28	First quarter Moon
29	Moon at descending node
30	Mercury and Venus conjunction

Resources

Calculating the habitable zone—*www.planetarybiology.com/calculating_habitable_zone.html*
Cassini Saturn mission—*http://saturn.jpl.nasa.gov*
Circumstellar Habitable Zones Lab—*http://astro.unl.edu/naap/habitablezones/habitablezones.html*
Complete list of exoplanets—*http://planetarybiology.com/exoexplorer_planets*
Distant worlds star mapper—*http://astronexus.com/endeavour/chart*
exoExplorer software—*www.planetarybiology.com/exoexplorer*
Exoplanet detection software—*www.compadre.org/OSP/items/detail.cfm?ID=10156*
Extreme Planet Makeover—*http://planetquest.jpl.nasa.gov/system/interactable/1/index.html*
Habitable zones in multiple star systems—*http://astro.twam.info/hz*
Meteor showers online—*http://meteorshowersonline.com*
Planet Habitability Laboratory habitable exoplanets catalog—*http://phl.upr.edu/hec*
Radius and volume of exoplanets—*www.rmg.co.uk/sites/default/files/media/pdf/KS4_Radius_and_Volume_of_Exoplanets.pdf*
Researchers develop model for identifying habitable zones around stars—*http://news.psu.edu/story/142653/2013/01/29/research/researchers-develop-model-identifying-habitable-zones-around-stars*
Riddle, B. 2014. Scope on the Skies: Anyone out there? *Science Scope* 38 (3): 82–87.
StarGen software—*http://eldacur.com/~brons/NerdCorner/StarGen/StarGen.html*
Square root calculator—*www.squarerootcalculator.co*
Super Planet Crash—*www.stefanom.org/spc/*

For students

1. What is meant by *absolute magnitude*? *(This is a brightness value given to all stars as if they were all located at 10 parsecs [32.6 light-years] from the Earth. This is not to be confused with a star's apparent magnitude, which is the brightness of a star based on the star's actual distance. In general, a more distant star appears less bright than a closer one.)*

2. How is the size of an exoplanet determined? *([Note: Ask your students' math teacher about their skill level before to see if this activity is appropriate.] While the formula sequence appears daunting, it simply relies on knowing the amount that the exoplanet's star's light decreases during transit. This percentage decrease is the same as the area of the planet's disk divided by the area of the star's disk. Depending on the planet and star values students are given to use, they could either work through the sequence of equations or just plug in the values at the last step (see Resources for more about calculating the size of exoplanets).*

   [a] *% light decrease = area of planet's disk / area of star's disk (Area = πr^2)*
   [b] *Calculate the area of the star and planet by first removing the value for pi from both sides:*

$$\frac{\text{planet } \pi r^2}{\text{star } \pi r^2} = \frac{\text{planet } r^2}{\text{star } r^2}$$

   [c] *% light decrease = area of planet divided by area of star × 100%)*

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